0010143963 & & *Drawing available*
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Electrical power transmission system with superconductor cables, includes inductive element made of superconductor which is connected in series with superconductor cable of each phase

Patent Assignee: LADIE P (LADI-I); NASSI M (NASS-I); PIRELLI CAVI & SISTEMI SPA (PIRE); PIRELLI CAVI E SISTEMI SPA (PIRE)
Inventor: LADIE P; LADIE' P; NASSI M

Patent Family (12 patents, 84 & countries)

Patent Number	Kind	Date	Application Number	Kind	Date	Update	Type
WO 2000039811	A1	20000706	WO 1999EP10442	A	19991222	200039	B
AU 200021034	A	20000731	AU 200021034	A	19991222	200050	E
BR 199916531	A	20011002	BR 199916531	A	19991222	200167	E
			WO 1999EP10442	A	19991222		
EP 1151442	A1	20011107	EP 1999965571	A	19991222	200168	E
			WO 1999EP10442	A	19991222		
US 20020019315	A1	20020214	US 1999115632	P	19990112	200214	E
			WO 1999EP10442	A	19991222		
			US 2001886043	A	20010622		
KR 2001092749	A	20011026	KR 2001707812	A	20010620	200223	E
CN 1331830	A	20020116	CN 1999814970	A	19991222	200230	E
NZ 512466	A	20020628	NZ 512466	A	19991222	200252	E
			WO 1999EP10442	A	19991222		
HU 200201622	A2	20020828	WO 1999EP10442	A	19991222	200264	E
			HU 20021622	A	19991222		
JP 2002534052	W	20021008	WO 1999EP10442	A	19991222	200281	E
			JP 2000591629	A	19991222		
AU 754643	B	20021121	AU 200021034	A	19991222	200305	E
US 6743984	B2	20040601	US 1999115632	P	19990112	200436	E
			WO 1999EP10442	A	19991222		
			US 2001886043	A	20010622		

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Patent Details

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WO 2000039811	A1	EN	37	5		
National Designated States,Original	AL AM AT AU AZ BA BB BG BR BY CA CH CN CU CZ DE DK EE ES FI GB GD GE GH GM HR HU ID IL IN IS JP KE KG KP KR KZ LC LK LR LS LT LU LV MD MG MK MN MW MX NO NZ PL PT RO RU SD SE SG SI SK SL TJ TM TR TT UA UG US					

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AU 200021034	A	EN			Based on OPI patent	WO 2000039811
BR 199916531	A	PT			PCT Application	WO 1999EP10442
					Based on OPI patent	WO 2000039811
EP 1151442	A1	EN			PCT Application	WO 1999EP10442
					Based on OPI patent	WO 2000039811
Regional Designated States,Original	AL AT BE CH CY DE DK ES FI FR GB GR IE IT LI LT LU LV MC MK NL PT RO SE SI					
US 20020019315	A1	EN			Related to Provisional	US 1999115632
					Continuation of application	WO 1999EP10442
NZ 512466	A	EN			PCT Application	WO 1999EP10442
					Based on OPI patent	WO 2000039811
HU 200201622	A2	HU			PCT Application	WO 1999EP10442
					Based on OPI patent	WO 2000039811
JP 2002534052	W	JA	35		PCT Application	WO 1999EP10442
					Based on OPI patent	WO 2000039811
AU 754643	B	EN			Previously issued patent	AU 200021034
					Based on OPI patent	WO 2000039811
US 6743984	B2	EN			Related to Provisional	US 1999115632
					Continuation of application	WO 1999EP10442

Alerting Abstract WO A1
NOVELTY - The nodes of electrical power transmission network are interconnected by the co-axial superconducting cables (104). An inductive element made of superconductor material is connected in series between the superconductor cables, for increasing reactance value of superconductor cable to predetermined value.
DESCRIPTION - An INDEPENDENT CLAIM is also included for co-axial superconductor cable installing method.
USE - Electrical power transmission system with superconductor cable.
ADVANTAGE - Provides co-axial superconductor cables having low impedance characteristics which forms preferential path for short circuit current, thus preventing the power transmission network from damage.
DESCRIPTION OF DRAWINGS - The figure shows the diagrammatic view of connection of superconductor cables.

Title Terms /Index Terms/Additional Words: ELECTRIC; POWER; TRANSMISSION; SYSTEM; SUPERCONDUCTING; CABLE; INDUCTIVE; ELEMENT; MADE; CONNECT; SERIES; PHASE

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[19]中华人民共和国国家知识产权局

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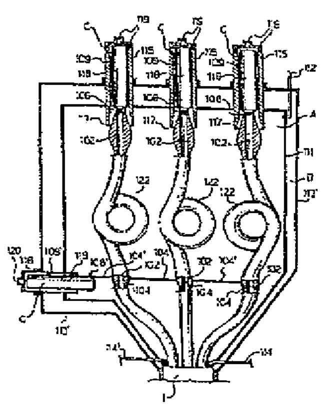
权利要求书 3 页 说明书 15 页 附图页数 3 页

[54]发明名称 使用超导体的电功率传输系统

[57]摘要

一般来说，本发明涉及一种使用超导体的电功率传输系统，它兼 容常用的传输系统。在第一个方案中，本发明涉及一种在电功率传输 系统中使用同轴超导电缆安装连接的方法，它包括下列步骤：确定适 用于上述连接的常用电缆的电抗；安装同轴超导电缆；增加同轴超导电缆的电抗使得超导电缆的电抗大致等于常用电缆的电抗。特别是，增加同轴超导电缆的电抗的步骤包括将同轴超导电缆与一电感元件相 串联，该电感元件最好由超导材料制成。



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权 利 要 求 书

1. 电功率传输网络，它包括：

网络的连接节点和上述节点之间的连接线；

同轴超导电缆，它与一第一电抗相连接，并连接在上述网络的两个节点之间；

其特征在于它还至少包括一电感元件，一第二电抗与电感元件相连接，电感元件与上述的同轴超导电缆相串联。

2. 如权利要求 1 所述的网络，其特征在于：上述第一电抗和上述第二电抗的和大致与一第三电抗值相等，第三电抗值基本上和适用于这种连接的常用电缆的电抗值相等。

3. 如权利要求 1 所述的网络，其特征在于：上述至少一个电感元件包括一超导电缆。

4. 如权利要求 1 所述的网络，其特征在于：上述至少一个电感元件包括一线芯。

5. 如权利要求 1 所述的网络，其特征在于：上述至少一个电感元件位于上述同轴超导电缆的一端。

6. 如权利要求 1 所述的网络，其特征在于：上述至少一个电感元件包括两部分，一部分位于上述超导电缆的一端，另一部分位于相对端。

7. 如权利要求 1 所述的网络，其特征在于：上述同轴超导电缆是多相型的。

8. 如权利要求 1 所述的网络，其特征在于：它至少包括一个与上述同轴超导电缆的每相串联的电感元件。

9. 如权利要求 1 所述的网络，其特征在于：上述同轴超导电缆包括一导电材料的支撑件。

10. 如权利要求 1 所述的网络，其特征在于：上述同轴超导电缆包括一复合材料的支撑件。

11. 一种在电功率传输系统中使用同轴超导电缆安装连接的方法，

其特征在于：它包括下列步骤：

确定适于上述连接的常用电缆的电抗；

安装具有设定电抗的上述同轴超导电缆；

增加上述同轴超导电缆的电抗使得上述超导电缆的上述电抗大致等于上述常用电缆的电抗。

12. 如权利要求 11 所述的方法，其特征在于：增加上述同轴超导电缆的电抗的步骤包括将上述同轴超导电缆与一电感元件相串联的步骤。

13. 如权利要求 12 所述的方法，其特征在于：上述电感元件是一超导体。

14. 如权利要求 11 所述的方法，其特征在于：它还包括步骤将一并行导电路径与上述同轴超导电缆相连接，使得上述同轴超导电缆所达到的最高温度低于超导材料的临界温度和在流体最小工作压力下的冷却液体的沸点之间的最低温度。

15. 一种在电功率传输系统中用同轴超导电缆连接代替常用电缆连接的方法，它包括下列步骤：

去除上述常用电缆；

安装上述同轴超导电缆；

其特征在于：它还包括增加上述同轴超导电缆的电抗的步骤。

16. 如权利要求 15 所述的方法，其特征在于：该方法还包括下列步骤：

确定适用于上述常用电缆的电抗；

增加上述同轴超导电缆的电抗使得上述超导电缆的上述电抗大致等于上述常用电缆的电抗。

17. 如权利要求 15 所述的方法，其特征在于：增加上述同轴超导电缆的电抗的步骤包括将上述同轴超导电缆与一电感元件相串联的步骤。

18. 如权利要求 17 所述的方法，其特征在于：上述电感元件包括超导体。

19. 如权利要求15所述的方法，其特征在于：该方法还包括步骤将并行导电路径与上述同轴超导电缆相连接，以便上述同轴超导电缆所达到的最高温度低于超导材料的临界温度和在流体最小工作压力下的冷却液体的沸点之间的最低温度。

20. 一种用于在室温下多相位电缆和电安装之间连接的热隔离终端，对于每相来说，上述电缆至少包括一同轴单元，该同轴单元具有一相超导体，一同轴返回超导体和一电绝缘介入层，还包括热控制件，它用于保持每个上述同轴单元的上述超导体处于超导状态，

上述终端的特征在于它包括一与每个相超导体相串联的电感元件。

21. 如权利要求20所述的终端，其特征在于：它包括：

至少一个壳体，

冷却件，

每个相超导体的通电电流引线，它具有在室温下与上述安装相连接的相应相连接器，

上述电流引线在相超导体和上述电流引线的连接器之间设有一电阻导体，上述电阻导体和上述相超导体之间的连接区域位于壳体的内部。

22. 如权利要求20所述的终端，其特征在于该终端包括：

一单个返回电流引线，它设有单个电阻返回导体，一与返回连接器相连接的顶端，该返回连接器用于在室温下与安装相连接；

在上述返回超导体和上述单个电阻返回导体之间的连接件，它由超导材料制成，

上述由超导材料制成的连接件和上述单个电阻返回导体之间的连接区域和至少在返回超导体和上述单个电阻返回导体之间的上述连接件处在壳体的内部，由于上述冷却件的存在，它们还处在低于临界温度以下的温度中，该临界温度与超导状态相对应。

01.06.22

说　　明　　书

使用超导体的电功率传输系统

一般来说，本发明涉及一种使用超导体的电功率传输系统，它兼容常用的传输系统。

正如大家所知，超导体通常是金属，合金，氧化物、化合物，它在某一温度以下，通常称之为临界温度，显示出其电阻值实际上下降为零。

特别是，超导体仅在其临界温度以下，临界磁场以下和临界电流密度以下将会保持超导性。

超导材料可以是低温型的，它们一般是如铌和钛合金的金属，或可以是高温型的，它们一般是那些以铋，锶，钙和铜氧化物（BSCCO）或钇、钡和铜氧化物（YBCO）为基础的陶瓷。

例如，对于这些其中之一的材料和其制成品来说，可以参考本申请人所拥有的欧洲专利 EP 646，974 中的描述。

在超导领域中，为了方便本申请的描述，术语“低温超导材料”表示具有 4^0K（大致为－269^0C）数量级工作温度的材料，“高温超导材料”表示具有 70－77^0K（大致为－203/－196^0C）数量级工作温度的材料。

为了能够在这些温度下工作，这些超导材料用合适的冷却液体，如低温的液态氦和高温的液态氮进行冷却。

为了方便本申请的描述，“常用电缆”表示使用具有非零电阻的导体的非超导电缆，特别是一种至少具有一非零电阻特性有效部分的电缆。电功率传输或配电网络通常包括一组由电缆或架空线组成的连接线，连接线以不同的方式（终端负载，回路或网状结构）连接，能够在与（电网连接线的）连接节点或与网络终端节点，如由电厂供电的分站，变压器站和用户负载相连接的单元之间传输电能。

传输网络偶尔也会产生过流，换句话说，会产生大于工作值的电

流，过流会在出现故障时，特别是在设备和线路出现短路时产生。在电缆中，这些过流不仅能够产生可损害没有与结构紧固的部件的电动力，而且能够产生一个非常大的温升，如果温度持续升高，将会导致绝缘体的燃烧和绝缘体（例如，变压器油）附近的可燃材料产生火灾。

在具有常用网络的设备安装中，过流保护是通过使用自动断路器提供的，通过自动断路和重接设备，在电流值等于设定值时断开电路，过流终止时重新接通电路。

为了保护这些断路器或在安装中出现的其它设备，如变压器，在其它系统中，就可能使用可以是电感型或电阻型的限流设备。

与所保护设备串接的限流器在正常工作的过程中具有较低的阻抗，但是网络发生过流时，它能够升高其电阻以限定电流在阈值以下而不会损坏断路器或变压器。公知的过流限流器包括电感，它们利用了材料的超导特性。在正常条件下，这些限流器，或限流器部件处于超导状态，设计成具有较低的阻抗。在产生过流时，它们会脱离超导状态，以具有高阻抗的方式工作。

例如，这种类型的限流器已在专利 US 5 140 290，US 5 546 261 和 EP 336 337 中描述。

对于常用的非超导电网，1953 年由 Vanini,Brescia 出版的 Filippo Tiberio 的书“Impianti elettrici”描述了电抗线圈的使用，电抗线圈或者与汇流排（串接在汇流条的两个部分之间）相连接，或者与线路相连接（换句话说在汇流条和远离电厂的线路之间）。

本申请人已注意到超导电缆安装通常是例如通过在两个网络节点之间用超导电缆代替常用电缆，或通过插入一新分段设置在常用网络中。

本申请人已注意到在使用超导体的传输系统和使用常用导体的传输系统之间存在兼容性的问题在现有技术中还没有解决。

更具体地说，本申请人已解决了如果发生短路在常用网络中使用同轴超导电缆传输系统工作过程中产生的问题。

本申请人已注意到同轴超导电缆引入网络中可能导致上述所讨论

的支路短路电流值的增加，这是因为与常用电缆相比，同轴超导电缆具有较低的特性阻抗值。

本申请人还注意到包括了同轴超导电缆，具有比常用线路更低特性阻抗的这种线路形成了一短路电流的最佳路径，包括它附近的线路，它必须比常用线路承受较大的电流。

同轴超导电缆的低特性阻抗是不仅由于它们具有较低的电阻，而且还具有较低的电抗。后者的值是一种对阻抗的绝对值具有最大影响的值。由于同轴超导电缆具有同轴结构，它的电抗就比较低，同轴超导电缆包括一相超导体（phase superconductor）和一返回超导体（return superconductor），返回超导体在与相超导体的反向传输大量与后者传输相等的电流。然而，在常用的非同轴电缆中，电抗是电缆几何特性的函数，还是一个电缆相对于其它电缆的相对位置的函数。

在这点上，本申请人解决了在过流的情况下保证同轴超导电缆与整个网络相兼容的问题。

本申请人还注意到短路对超导电缆会产生一些问题。特别是，注意到在短路的情况下，超导体从超导状态转换为正常导电状态，换句话说就是电阻状态；在此情况下，由焦耳效应产生的热发散增加非常大，因此随着冷却液体的潜在蒸发，电缆的温度就会升高。恢复正常工作条件时，换句话说在短路的后期，超导体必须返回至额定的工作温度，换句话说它必须冷却降温以返回至超导状态。这就意味着超导电缆在恢复短路时不能立即正确工作，因为它必须进行等待以便冷却和返回至超导状态。

在使用常用电缆和同轴超导电缆的网络中所出现的上述问题，本申请人已意识到通过使过流情况下的同轴超导线路的电特性大致等效于使用常用电缆的模拟线路的特性来解决这些问题，或无论如何简化这些问题。

更详细地说，本申请人已意识到对于上述问题最重要的超导线路的电值是电缆的感抗，在同轴超导电缆中这个值显著地低于常用电缆中的值。

更详细地说，本申请人已发现所述问题的解决方案通过在相同的工作条件下将同轴超导电缆的感抗值升高至等于或接近于常用电缆的感抗值而获得。

本发明的一个实施例包括与电感元件的同轴超导电缆串接的连接，该电感元件具有一个电抗值使得电抗的总值（对于电缆和电感器来说）设成等于或接近于相同连接的常用电缆的电抗值。

本申请人已发现这种方案使它能够获得超导线路与常用网络的完全兼容。

根据本发明的另一个方案，本申请人还发现，在过流的情况下，为了避免超导电缆过热，超导体从超导状态转换为正常传导的状态，电缆必须设有与超导电缆并行的附加电流路径。

本申请人还注意到使用本发明的方案时，它不必向包括超导线路的网络提供保护设备，这些保护设备不同于（换句话说它们能够承受和抑制较大的电流）用于包括常用线路的相同网络中的那些设备。

在第一个方案中，本发明涉及一种电功率传输网络，它包括:

网络的相互连接的节点和所述节点之间的连接线;

一同轴超导电缆，它与一第一电抗相连接，连接在上述网络的两个节点之间;

其特征在于: 它还至少包括一电感元件，电感元件与一第二电抗相连接，并与上述同轴超导电缆串联。

最佳方案是，上述第一电抗和上述第二电抗的总和大致与适用于这种连接的常用电缆的电抗相等。

更具体地说，上述至少一个电感器包括一个超导电缆，还可包括一线芯。

上述至少一个电感器位于上述同轴超导电缆的一端，或者另一种情况是包括两个部分，其中的一部分位于上述同轴超导电缆的一端，另一部分位于相对端。

在一个实施例中，上述同轴超导电缆是多相位型的，至少包括一个电感器，它与上述同轴超导电缆每相串联。

在一个最佳实施例中，上述同轴超导电缆包括一导电材料的支架，在另一个实施例中，它包括一复合材料的支架。

在第二个方案中，本发明涉及一种在电功率传输系统中使用同轴超导电缆安装连接的方法，其特征在于，它包括下列步骤：

- 确定适用于上述连接的常用电缆的电抗；
- 安装具有设定电抗的上述同轴超导电缆；
- 增加上述同轴超导电缆的电抗使得上述超导电缆的上述电抗大致等于上述常用电缆的电抗。

更具体地说，增加上述同轴超导电缆的电抗的步骤包括步骤将上述同轴超导电缆与一电感元件相串联，该电感元件最好由超导材料制成。

最好情况是，根据本发明的另一个方案，该方法还包括步骤将设定电阻的并行导电路径与上述同轴超导电缆相连接，使得短路电流分布在上述超导电缆和上述导电路径之间，以使上述同轴超导电缆所达到的最高温度低于超导材料的临界温度和在流体最小工作压力下的冷却液体的沸点之间的最低温度。

在第三个方案中，本发明涉及一种在电功率传输系统中用同轴超导电缆连接代替常用电缆连接的方法，它包括下列步骤：

- 去除上述常用电缆；
- 安装上述同轴超导电缆；

其特征在于：它还包括增加上述同轴超导电缆的电抗的步骤。

最好是，该方法还包括下列步骤：

- 确定适用于上述常用电缆的电抗；
- 增加上述同轴超导电缆的电抗使得上述超导电缆的上述电抗大致等于上述常用电缆的电抗。

更具体地说，增加上述同轴超导电缆的电抗的步骤包括步骤将上述同轴超导电缆与一电感元件相串联，该电感元件最好由超导材料制成。

最好情况是，该方法还包括步骤将并行导电路径与上述同轴超导

电缆相连接，使得上述同轴超导电缆所达到的最高温度低于超导材料的临界温度和在流体最小工作压力下的冷却液体的沸点之间的最低温度。

在第四个方案中，本发明涉及一种用于在室温下多相位电缆和电气安装之间连接的热绝缘终端，对于每相来说，上述电缆至少包括一同轴单元，该同轴单元具有一相超导体，一同轴返回超导体和一电绝缘介入层，还包括热控制件，它用于保持每个上述同轴单元的上述超导体处于超导状态，

上述终端的特征在于它包括一与每个相超导体相串联的电感器。

最好是，该终端包括：

- 至少一个壳体
- 冷却件，
- 每个相超导体的通电引线，它具有在室温下与上述安装相连接的相应相连接器，

上述电流引线在相超导体和上述电流引线的连接器之间设有一电阻导体，上述电阻导体和上述相超导体之间的连接区域位于壳体的内部。

最好是，该终端包括：

- 单个返回电流引线，它设有一单个电阻返回导体，具有一与返回连接器相连接的顶端用于在室温下与安装相连接；
- 在上述返回超导体和上述单个电阻返回导体之间的连接件，它由超导材料制成，

上述由超导材料制成的连接件和上述单个电阻返回导体之间的连接区域，和至少在返回超导体和上述单个电阻返回导体之间的上述连接件处在壳体的内部，由于上述冷却件的存在，它们还处在低于临界温度以下的温度中，该临界温度与超导状态相对应。

本发明借助于下面其实施例的描述和附图将会变得更明清楚明白。

图 1 表示三相的超导电缆；

图 2 表示三个同轴超导电缆的连接终端;

图 3 表示根据本发明一个实施例的分布线路的大致示图;

图 4 表示根据本发明一个实施例的图 2 中终端的示图;

图 5 表示放射传输线的大致示图。

参考图 1，根据本发明的三相超导电缆 1 的一个实例包括三个导电元件 C，分别用 C1，C2，和 C2 表示，每个用于每相，且最好宽松地容设在管状容置壳体 8 内，例如壳体由如钢，铝等金属材料制成。

每个导电元件 C 依次包括一对同轴导体，即相导体 2 和返回导体 4，每个导体至少包括一超导材料层。

同轴相导体 2 和返回导体 4 通过插入介电材料层 3 相互形成电绝缘。在图示的实例中，超导材料包含在许多重叠条中，重叠条分别缠绕在支撑件 5 和电绝缘层 3 上。

电缆 1 还包括合适的部件，用于冷却超导导体 2 和 4 以使它们的温度充分低于前面所选择的超导材料的临界温度，其中图 1 中的电缆是所谓的“高温”型。

前述的部件包括适当的泵装置，从它自身来说是公知的，因此未图示，其目的是向每个导电元件 C 的内部 F1 和这些元件与管状壳体 8 之间的空隙 F2 中馈送适当的冷却液体，例如通常其温度范围为 65^0－90^0K 的液态氮。

在返回导体 4 的外侧有一短路用的金属保护元件 6 和一机械保护元件 7。

为了尽可能地减少向外部环境的热扩散，超导体被封闭在一个容器结构或低温恒温箱中，该低温恒温箱包括一隔热器，例如它由多个绝热材料的重叠层和至少一保护套组成。

在例如 IEEE 电力输送学报第 7 卷第 4 期（1992 年 10 月）第 1745－1753 页上的文章中描述了本领域公知的低温恒温箱。

更具体地说，在图示的实例中，低温恒温箱包含一绝缘材料层 9，例如由表面敷以金属的塑料材料（例如聚酯树脂）构成的若干条带（几十个）所组成，在本领域中称之为“超级热绝缘体”，这些条带宽松

地缠绕，若需要可借助放在中间的隔离件（未图示）。

这些条带放置在环状间隙中，该间隙由壳体 8 和管状部件 10 限定，其中，由公知的装置保持 $10^{-2}N/m^2$ 数量级的真空。

金属管状部件 10 能够给这环状间隙以所希望的不可渗透性，并由一外壳 11 罩住，该外壳例如由聚乙烯构成。

金属管状部件 10 最好由钢、铜、铝等构成的条带缠绕成管状并纵向焊接而成、或者由挤压成形的管子或相似部件构成。

如果需要使电缆具有柔性，部件 10 可做成波纹状。

在一个实施例中，电缆的超导材料由基于超导体的条带构成，超导体是公知的陶瓷型高温超导体。

更具体地说，在本实施例中，超导体条带以相对于电缆的方向的缠绕角度缠绕在直径为 15－80mm 的管状柱形支撑件 5 和电绝缘层 3 上，缠绕角度在条带之间和每个条带内部是固定的或可变的，通常在 10^0-60^0 范围内。

这种高温超导条带包括由银或类似金属的合金制成的壳体中的超导材料，在本领域中用公知的符号 BSCC0 表示，具有以下的分子式可使用：

$Bi_{\alpha}Pb_{\beta}Sr_{\gamma}Ca_{\delta}Cu_{\varepsilon}O_{\chi}$

其中：

α 数值在 1.4 到 2.0 之间； β 数值在 0 到 0.6 之间；

γ 数值在 1.5 到 2.5 之间； δ 数值在 0 到 2.5 之间；

ε 数值在 1.0 到 4.0 之间； x 是相应于存在的不同氧化物的化学计算值。

根据本发明，如果它希望在短路后具有一个迅速的，或者甚至是瞬时的超导电缆的恢复时间，或者换句话说具有一个限定超导电缆温度升高的恢复时间，管状柱形支撑件 5 和保护层 6 最好就由导电材料，例如适当尺寸的铜或铝构成。部件 5 和 6 与超导电缆的条带相耦合以便在它们之间形成电连接。这样，即使发生过流，超导体也会转换为电阻状态，过流在平行于由金属部件 5 和 6 构成的超导电缆的导电路

径中流通。部件 5 和 6 中的金属导电材料的数量要使超导电缆所达到的最高温度，对于一设定的安全边缘来说，低于超导材料的临界温度与在冷却液体最小工作压力情况下冷却液体（氮）的沸点之间的最低温度。

最好是，超导条带至少包括一由金属材料（不锈钢，青铜，铍或铝）制成的加强带（未图示），该加强带与条带的金属涂层相连接。这种加强带的存在使它能够在电缆安装或使用过程中增加电缆抵抗施加给它的各种机械或热应力。

根据本发明的另一个实施例，支撑件 5 是复合型的，它包括若干由金属材料和塑料材料（例如 Teflon）制成的相邻环形扇段。因此，这种部件 5 具有一个大于超导材料的热膨胀系数，所以它在电缆的冷却过程中能够以大于超导材料的程度收缩，而不会通过干涉它在超导材料的内部产生应力。

金属和塑料扇段的数量及这些扇段的位置由本领域的技术人员根据电缆的设计需求而确定。

最好是，支撑件 5 可同时实现许多功能。其中之一的功能是限制超导材料层在长度方向上产生变形，这种变形是由于超导电缆在安装后（在室温下）其冷却过程中阻碍热膨胀产生的。一种是机械地支撑超导材料，另一种是减小由超导电缆的端部施加给电缆终端的应力，而同时在瞬时短路过程中提供足够的金属以稳固电缆。

一种三相型的同轴超导电缆已通过实例作出描述，但其它类型的电缆根据本发明也可以使用，例如，单相电缆，或单件电缆（换句话说是每相分离的电缆）；低温恒温箱也可以用不同的，例如在室温下保持电绝缘的材料制成。

超导电缆通常通过连接终端与分站或配电或传输网络的变压器站相连接，例如，连接终端已在以本申请人名义的欧洲专利申请 EP 780926 中作了描述。

上述专利申请所描述的一种用于连接三个冷却至它们临界温度以下的单相同轴超导电缆和室温下相应终端的终端，如图 2 所示。

这里没有描述冷却电缆和终端的系统，因为它对于本领域的技术人员来说是熟知的。

该终端主要包括一冷却区 A，在冷却区 A 内电缆各部分保持在低于超导临界温度以下，一围绕 A 区的绝热区 B，一热控区 C，其中设有用于阻止从外部室温向电缆的冷却区进行热穿透的器件。

图 2 的下方表示三根同轴电缆进入终端的的入口，每根电缆是单相型的，属于单件电缆 1。

更具体地说，每根通电的相超导体 102 延伸到冷却区中，并通过端子夹 108 与电阻导体 109 相连接；转而，导体 109 穿过热控区 C，最后与室温电气设备的连接器 119 相连接。

从三根返回超导体 104 的入口进入冷却区，它们就通过超导连接件 104' 相连接，通过夹子 108' 与由电阻导体 109' 形成的单个电流引线相连接，以和其它相导体相同的方式经过连接器 102 延伸向外部。

超导连接件包括基于返回导体的末端的具体结构形成的超导元件。

从图 2 中将会明白，终端的冷却区是由金属材料的壳体 111 限定形成的，冷却液体，最好是温度大约为 -200^0C 的液态氮通过一入口管 112 注入壳体中。

在设定温度下液态氮注入壳体中，壳体周围的热隔离度是以壳体冷却区的温度总是低于临界温度以下的方式进行控制的，换句话说高于该温度超导体将不处于超导状态。

壳体周围的绝热区由壳体周围用于限定一空间的容器 113 提供，其中保持真空。

三根单芯电缆通入容器和壳体的入口，每根电缆通过由图示的入口管 114 和出口管 114' 在壳体内部循环的液态氮保持在临界温度以下。

相导体 109 和返回导体 109' 穿过壳体和容器的外壳，分别容置在高压和低压绝缘体 115 和 116 中。

每个绝缘体内表面的下端为截头圆锥形，与围绕相超导体的偏转

锥体 117 分离间隔，其目的是控制电场。

现在将研究一种电功率的传输/配电系统，作为解释用，它的大致示图如图 3 所示。

该网络包括若干电缆 20，30，40，50，60，70 和 80，它们在节点 42 和节点 43 之间延伸，节点 42 与发电机 41 相连接，节点 43 与任一种负载 44 相连接。

电缆 20，30，40，50，60，70 和 80 可认为由常用的非超导电缆构成，特性阻抗与该电缆相关。

现在假定常用电缆 60 用等长的同轴超导电缆代替。

超导电缆本来就具有一特性阻抗，它比所替代的常用电缆的特性阻抗小得多。

在短路的情况下，例如在节点 43 接近地电势的情况下，将会在节点 42 和节点 43 之间存在（短路）电流的流动，该电流流过网络的导体。由于电缆 60（实际上具有零阻抗）和其余电缆之间存在阻抗差，绝大多数电流将会在电缆 60 中流过。

这也会在与电缆 60 相连接的电缆中产生非常大的电流负载；特别是，将会有非常大的电流流入电缆 20 和 30 中，该电流大于电缆全部都是常用型所产生的电流，因此可能会对网络产生损坏。

如果一种新的同轴超导电缆加在网络中，也会发生相同的情况，例如在发电机 41 和节点 42 之间加入一段。

更具体地说，现已计算出如果复合网络分布区（例如为主要市区中心供电需要）由超导电缆构成，相对于如果该网络由常用电缆构成，短路电流将会增加高达 70%。

根据本发明，本申请人已发现这些问题通过使过流情况下的同轴超导线路的电特性大致与使用常用电缆的同样线路的电特性相同而加以解决。

特别是，现已发现通过将同轴超导电缆与具有一电抗值的电感元件相串联以使电抗的总值（对于电缆和电感器来说）等于或接近于相同连接的常用电缆的电抗值（具有相同数量级的值），过流情况下网

络的特性会恢复到该网络全部由常用型电缆组成时所出现的特性。

图 4 表示根据本发明的连接终端的一个具体实施例，它包括一个终端，与前面参考图 2 所描述所终端相似。在图 4 中，与图 2 中相同的参考标号用于表示相同的部件。

图 4 的下端表示属于电缆 1 的三根同轴电缆终端的入口。由入口进入冷却区 A 的三根返回超导体 104 通过超导连接件 104' 相连接，通过夹子 108' 与由电阻导体 109' 形成的单个电流引线相连接，其经过连接器 102 延伸向外部。

三根适当尺寸的在壳体 113' 内延伸的相超导体 102 可缠绕为形成三个具有上述设定值的电抗线圈 122。

三个线圈 122 最好能以避免产生互感的方式定位。

与参考图 2 描述终端的方式相同，每根通电的相超导体 102 延伸到冷却区 A 中，并通过端子夹 108 与电阻导体 109 相连接；转而，导体 109 穿过热控区 C，最后与室温电气设备的连接器 119 相连接。

电抗线圈 122 最好位于终端内部，但也可以位于沿超导电缆的任意点上。此外，由于尺寸或其它不同因素的问题，电抗线圈 122，例如也可以分布在两个终端之间（例如通过将电抗分为两部分），在任何情况下，也可分为若干部分，并位于沿超导电缆的若干点上。

下面表示根据本发明的一种设计连接线路方法的数值实例。

图 5 大致表示与网络 100 相连接的发电机 41，连接线 90 将网络 100 与负载 44 相连接。

线路 90 所作的连接具有下面的特性参数:

功率 P=108 MVA

电压 V= 115 kV

频率 f= 60Hz

长度 L= 8 km

使用这些参数，用本领域技术人员熟知的方法，能以一第一近似法确定适于这种连接的电缆的特性。

术语“适于这种连接的常用电缆”表示一种能够在具有设定特性

参数的连接中传输电功率的电缆。例如，连接的主要特性参数，如上面所列举的那些，即功率，电压，频率和长度，在第一近似法中使用公知的方法用于确定适于这种连接的三相组的三根电缆的电缆截面。因此它能够使用公知的方法确定单根电缆的电抗。

用常用电缆说明上面连接的一个可能实施例包括使用一组具有 $500mm^2$ 截面的三根铜电缆。

在此情况下，由导体的类型和与其它导体的接近程度确定的单根常用电缆的感抗是:

$$X_{conv} = 0.16\ \Omega/km$$

如果现在假定 5000A 的短路电流从外部网络 100 到连接线 90 上，通过本领域技术人员熟知的计算方法，发现在连接线 90 的末端，换句话说靠近负载 44 的端部将会产生大约为 4190A 的过流。

上面所述的连接线 90，如果它由一组三根同轴超导电缆形成，具有单根超导电缆的感抗，它的值等于:

$$X_{sup} = 0.0264\ \Omega/km$$

本申请人已注意到同轴超导电缆的电抗值大大低于常用电缆的电抗值，在图示的实例中，大约是常用电缆电抗值的六分之一。

现在再假定 5000A 的短路电流从网络 100 的外部到连接线 90，在此情况下，连接线由同轴超导电缆形成，在连接线的末端就会产生大约为 4500A 的过流，与前述情况相比大约增加了 7%。

根据本发明，电缆的三根返回超导体以参考图 4 所述的方式连接在一起，并与接地极相连接后，在每相的导体上就会形成一螺旋管线圈，并具有下面的电抗:

$$X_{add} = X_{conv} - X_{sup} = (0.16 - 0.0264)\ \Omega/km = 0.1336\ \Omega/km$$

因此具有下面的电感

$$L_{add} = X_{add}/(2\pi f) = 0.354\ mH/km$$

其中

X_{add} 表示与每公里单相连接线串联的电抗;

X_{conv} 表示每公里连接线的常用电缆的电抗;

Xsup 表示每公里连接线的同轴超导电缆的电抗；

Ladd 表示与每公里单相连接线串联的电感。

这样，就会获得与常用电缆相同的效果，换句话说就能够消除上述短路电流值的增加。因此，连接线 90 在短路出现时的特性就与用常用电缆构成的一样。

例如，通过用每相超导电缆的引出导体构成一螺旋管线圈，就能获得一具有 Ladd = 0.354 mH/km × 8 km = 2.83 mH 的电感元件。这种螺旋管线圈的特性是：

匝数 = 26

匝半径 = 1.5m

绕组高度 = 2m

导体长度 = 245m

根据本发明的另一个实施例，这种附加电感元件可包括一具有适当磁心的螺旋管线圈，其特性例如为：

匝数 = 1

匝半径 = 0.5m

绕组高度≤2m

导体长度 = 3.14m

在此实例中，假定同轴超导电缆与一电抗相串联，电抗的值是常用电缆的电抗值与超导电缆的电抗值之差，这样，适于这种连接的常用电缆的电抗值大致与超导电缆的电抗值相等。然而，它通过许可能够连接其电抗值是前述电抗值几分之一（例如二分之一）的电抗，如果系统设备容许，短路电流就会相应的增大。例如，如果其值是常用电缆电抗值二分之一的电抗：

Xadd 1= （Xconv－Xsup）/2 = (0.16－0.0264)/2 Ω/km = 0.0668 Ω/km

连接在上述的连接线中，短路电流大约增加 4%。

它也能将同轴超导电缆与一电抗相串联，该电抗的值使得其总电抗值大于常用电缆的电抗值以便比常用电缆提供更好的工作特性。在

任何情况下，为了使用同轴超导电缆进行连接，同轴超导电缆基本上能够兼容适于这种连接的等效常用电缆，超导电缆的电抗就必须被增大，最好必须与常用电缆具有相同数量级的值。

本申请人注意到附加电感元件最好可位于相超导体的任意端，最好位于超导电缆与室温下的常用电缆相连接的终端的区域中。

根据另一个实施例，它能够使用位于相超导体两端的两个附加电感元件，该电感元件的总电感值与上述所确定的值相等。

上述电感元件也可由位于室温下空气中的常用导体形成（例如由铜形成）。

然而，本申请人注意到如果电感元件是用相同的超导电缆而不是导体形成，它就具有特别的效果。这是因为这种方法能够显著地减少用于形成螺旋管线圈的导体全长所产生的电阻损耗。在上述的情况下，由截面积为 500^2mm 的铜导体形成的螺旋管线圈的损耗，例如，其数量级是 12W/m/相，而由超导体形成的螺旋管线圈的损耗，其数量级是 6W/m/相（包括冷却效率）。

此外，超导电缆和附加的电感元件最好都具有上述的金属或复合型的支架。

说 明 书 附 图

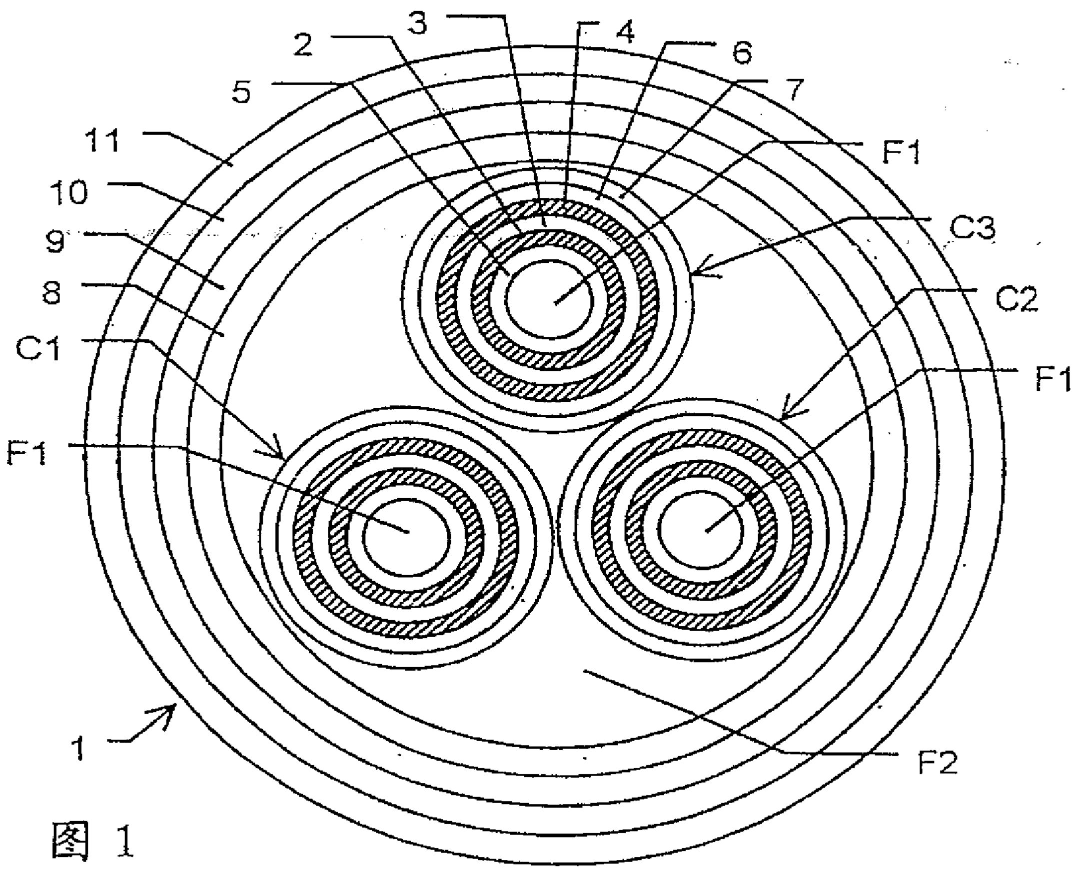


图 1

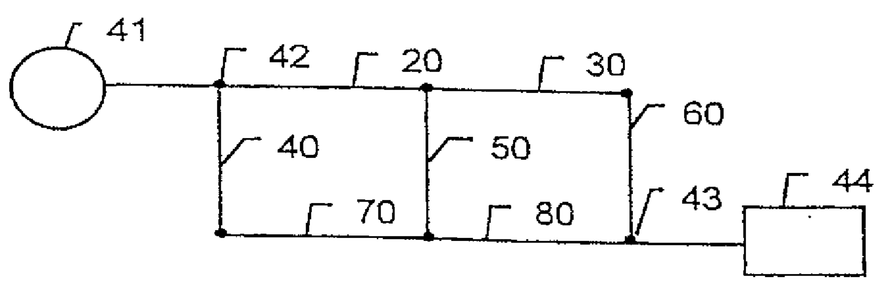


图 3

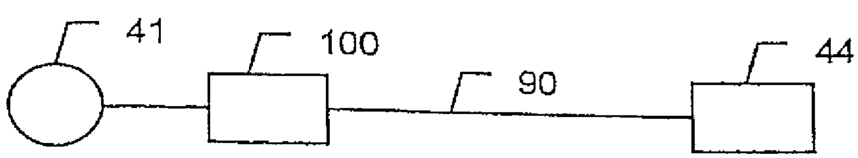
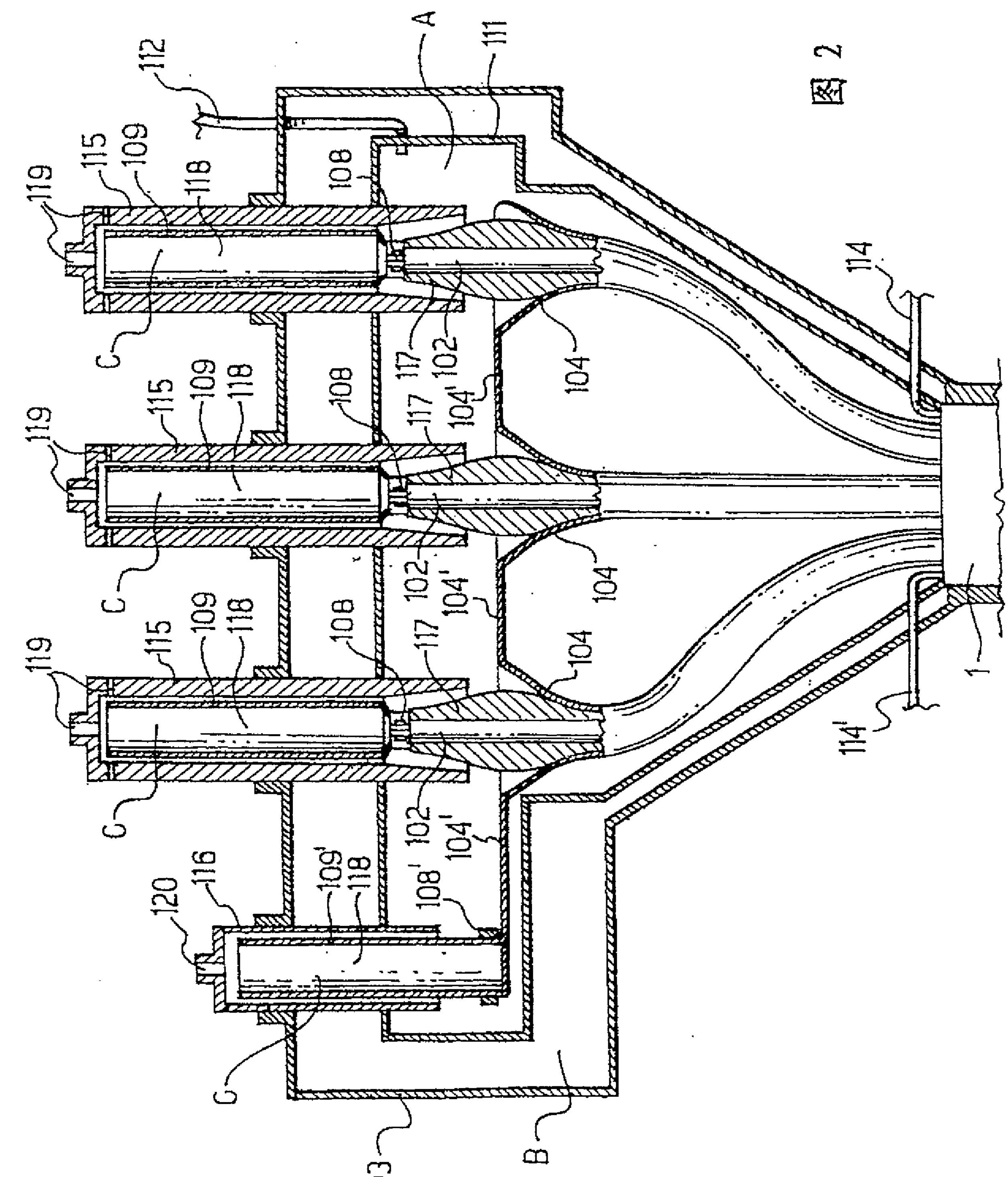


图 5

01·06·22



A
111
112
119
115
109
118
108
C
117
102
104
104'
1
114
114'
120
116
109'
108'
G
113
B

图 2

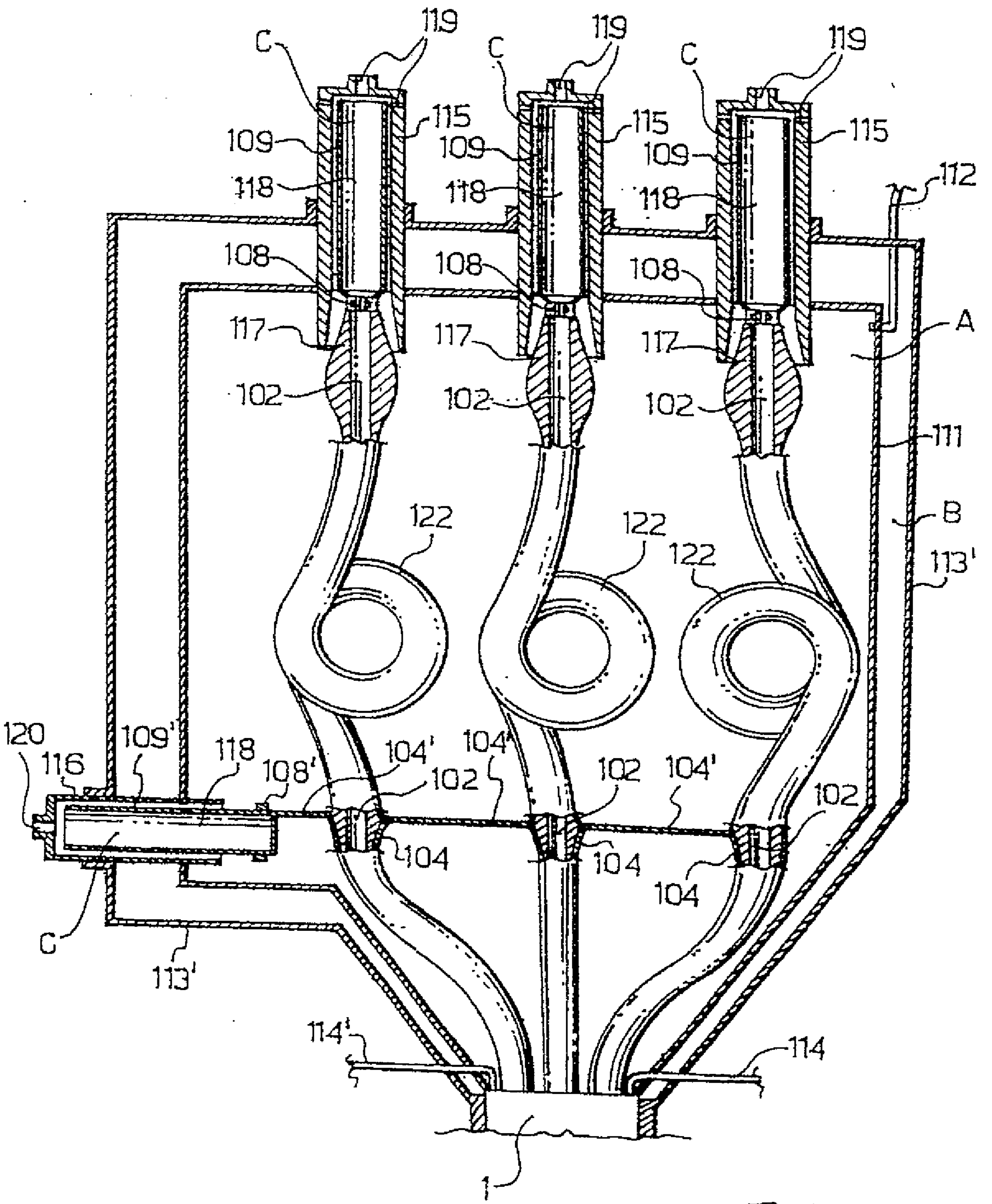

119
C
115
109
118
108
117
102
112
A
111
B
113'
122
120
116
109'
108'
104'
104
C
114'
114
1

图 4

English Translation of the reference 1 (CN1331830A)

ELECTRICAL POWER TRANSMISSION SYSTEM USING SUPERCONDUCTORS

In general terms, the present invention relates to an electrical power transmission system using superconductors which is compatible with conventional transmission systems.

As is known, superconductors are metals, alloys, oxides, and, in general, compounds which, below a temperature normally referred to as the critical temperature, show a fall in resistivity to practically zero values.

In particular, a superconductor will remain superconducting only below its critical temperature, below a critical magnetic field, and below a critical current density.

Superconducting materials may be of the low-temperature type, which are generally metals such as alloys of niobium and titanium, or of the high-temperature type, which are generally ceramics such as those based on bismuth, strontium, calcium and copper oxides (BSCCO) or yttrium, barium and copper oxides (YBCO).

Reference may be made, by way of example, for one of these materials and for its preparation, to the description in European Patent EP 646 974 held by the present Applicant.

In the field of superconductors and for the purposes of the present description, the term"low-temperature superconducting materials"denotes materials having an operating temperature of the order of 4 K (approximately269 C), and"high-temperature superconducting materials" denote materials having an operating temperature of the order of 70-77 K (approximately-203/-196 C).

In order to operate at these temperatures, these superconductors are cooled with suitable coolant fluids, such as liquid helium for the low temperatures and liquid nitrogen for the high temperatures.

For the purposes of the present description,"conventional cable"denotes a non-superconducting cable using electrical conductors with non-zero resistance, in particular a cable which has at least a significant portion with characteristics of non-zero electrical resistance. An electrical power transmission or distribution network generally comprises a set of connecting lines consisting of cables or overhead lines, connected in different ways (in terminal load, loop, or mesh configuration) and capable of carrying energy between units connected to interconnection nodes (of the

connecting lines of the network) or to terminal nodes of the network, such as sub-stations supplied by electrical power plants, transformer stations and user loads.

Transmission networks may occasionally be subjected to overcurrents, in other words currents having a value higher than the operating value, which occur in the presence of faults and particularly in the presence of short circuits of the equipment and particularly of the lines. In the cables, these overcurrents may cause not only electrodynamic forces capable of damaging parts not securely fixed to the structures, but also an excessive temperature rise which, if persistent, may result in the burning of insulators and fires in combustible materials close to the insulators (transformer oil, for example).

In installations with conventional networks, overcurrent protection is provided by the use of automatic circuit breakers which, by means of an automatic cut-out and reconnection device, open the circuit at a current value equal to a set value and reclose the circuit when the overcurrent ceases.

For the protection of these circuit breakers or other equipment present in an installation, such as transformers, it is possible to use, among other systems, current limiting devices which may be of the induction or resistance type.

The current limiter, installed in series with the equipment to be protected, has a low impedance during normal operation, but when an overcurrent occurs in the network it increases its impedance in such a way as to limit the current to below a threshold value so as not to damage the circuit breaker or transformer. There are known overcurrent limiters, comprising inductances, which make use of the superconductivity characteristics of the materials. Under normal conditions, these limiters, or parts of them, are in a superconducting state and are designed in such a way that they have a low impedance. In the presence of overcurrents, they leave the superconducting state and behave in such a way as to have a high impedance.

Limiters of this type are described, for example, in the patents US 5 140 290, US 5 546 261 and EP 336 337.

The book"Impianti elettrici", by Filippo Tiberio, Published by Vanini, Brescia, 1953, describes, for conventional non-superconducting networks, the use of reactance coils which are connected either to the busbars (in series between two sections of bar) or to the lines (in other words between the bars and the lines departing from the power plant).

The Applicant has observed that superconducting cable installations are typically intended to be provided within a conventional network, for example by replacing a conventional cable with a superconducting cable between two nodes of the network, or by inserting a new section.

The Applicant has observed that the problem of the compatibility between transmission systems using superconductors and transmission systems using conventional conductors has not been tackled in the prior art.

In particular, the Applicant has tackled the problem of the behavior of transmission systems using coaxial superconducting cables inside a conventional network in case of a short circuit.

The Applicant has noted that the introduction of a coaxial superconducting cable into a network might lead to an increase in the value of the short-circuit current in the branch in question as a result of the lower value of the characteristic impedance of the coaxial superconducting cable by comparison with that of a conventional cable.

It has also noted that the line comprising the coaxial superconducting cable, having a lower characteristic impedance than that of conventional lines, forms a preferential path for the short-circuit currents, involving the lines close to it which might have to withstand a higher current than a conventional line.

The low characteristic impedance of coaxial superconducting cables is due to their low resistance and also to their low reactance. The latter value is the one which has most effect on the absolute value of the impedance. The reactance of a coaxial superconducting cable is low owing to its coaxial structure, which comprises a phase superconductor and a return superconductor which carries in the opposite direction to the phase conductor a quantity of current equivalent to that carried by the latter. In conventional non-coaxial cables, however, the reactance is a function of the geometrical characteristics of the cable and also of the relative positioning of one cable with respect to the others.

At this point, the Applicant tackled the problem of ensuring the compatibility of a coaxial superconducting cable, in the presence of overcurrents, with the whole network.

The Applicant has also observed that short circuits create problems for superconducting cables. In particular, it has observed that in the presence of a short circuit the superconductor passes from the superconducting state to the state of normal conduction, in other words the resistive state; in this state, the emission of heat by the Joule effect increases considerably, and consequently there is an increase in the temperature of the cable with potential evaporation of the coolant liquid. When normal operating conditions are restored, in other words at the end of the short circuit, the superconductor must return to the nominal operating temperature, in other words it must cool down, to return to the superconducting state. This means that the superconducting cable cannot operate correctly immediately on the restoration of the short circuit, since it is necessary to wait for it to cool and return to the

superconducting state.

Given the aforementioned problems in a network using conventional cables and coaxial superconducting cables, the Applicant has realized that the problems can be resolved, or in any case diminished, by making the electrical behavior of the coaxial superconducting lines in the presence of overcurrents substantially equivalent to the behavior of analogous lines using conventional cables.

In greater detail, the Applicant has realized that the electrical value of the superconducting line which is most important for the problems stated previously is the inductive reactance of the cables which constitue it, this value being significantly lower in coaxial superconducting cables than in conventional cables.

Even more particularly, the Applicant has found that a solution to the reported problems is obtained by raising the value of the inductive reactance of the coaxial superconducting cable to a value equal or close to that of a conventional cable in the same operating conditions.

An embodiment of the present invention comprises the connection in series with the coaxial superconducting cable of an inductive element having a value of reactance such that the total value of reactance (for the cable and the inductor) is made equal or close to that of a conventional cable for the same connection.

The Applicant has found that this solution makes it possible to obtain complete compatibility of the superconducting line with a conventional network.

According to another aspect of the present invention, the Applicant has also found that, in order to prevent the superconducting cable from overheating when, in the presence of overcurrents, the superconductor passes from the superconducting state to the state of normal conduction, the cable has to be provided with an additional current path in parallel with the superconducting cable.

The Applicant has further noted that when the teachings of the invention are applied it becomes unnecessary to provide the network comprising superconducting lines with protective devices which are different (in other words capable of withstanding and stopping higher currents) from those used for the similar network comprising conventional lines.

In a first aspect, the present invention relates to an electrical power transmission network comprising: interconnecting nodes of the network and connecting lines between the said nodes; a coaxial superconducting cable with which is associated a first reactance, connected between two nodes of the said network; characterized in that it also comprises at least one inductive element, with which is associated a second

reactance, connected in series with the said coaxial superconducting cable.

Preferably, the sum of the said first reactance and the said second reactance is substantially equal to a third reactance whose value is substantially equal to the reactance of a conventional cable suitable for such a connection.

In particular, the said at least one inductor comprises a superconducting cable, and may also comprise a core.

The said at least one inductor is located at one end of the said coaxial superconducting cable, or alternatively comprises two parts, of which one is located at one end of the said superconducting cable and the other is located at the opposite end.

In one embodiment, the said coaxial superconducting cable is of the multiple-phase type, and comprises at least one inductor connected in series with each phase of the said coaxial superconducting cable.

In an advantageous embodiment, the said coaxial superconducting cable comprises a support of conducting material and, in an alternative embodiment, a support of composite material.

In a second aspect, the present invention relates to a method for installing in an electrical power transmission system a connection using a coaxial superconducting cable, characterized in that it comprises the following steps: determining the reactance of a conventional cable suitable for the said connection; -installing the said coaxial superconducting cable having a predetermined reactance; -increasing the reactance of the said coaxial superconducting cable, in such a way that the said reactance of the said superconducting cable is substantially equal to the reactance of the said conventional cable.

In particular, the step of increasing the reactance of the said coaxial superconducting cable comprises the step of connecting in series with the said coaxial superconducting cable an inductive element, preferably made from a superconducting material.

Advantageously, according to another aspect of the present invention, the method also comprises the step of associating with the said coaxial superconducting cable a parallel conducting path of predetermined resistance, so that the short-circuit current is distributed between the said superconducting cable and the said conducting path in such a way that the maximum temperature reached by the said coaxial superconducting cable is lower than the minimum temperature between the critical temperature of the superconducting material and the boiling point of the coolant fluid at the minimum working pressure of the fluid.

In a third aspect, the present invention relates to a method for replacing, in an

electrical power transmission system, a conventional cable connection with a coaxial superconducting cable connection, comprising the following steps: -removing the said conventional cable; -installing the said coaxial superconducting cable; characterized in that it additionally comprises the step of increasing the reactance of the said coaxial superconducting cable.

Preferably, the method additionally comprises the step of: -determining the reactance of the said conventional cable; -increasing the reactance of the said coaxial superconducting cable in such a way that the reactance of the said coaxial superconducting cable is substantially equal to the reactance of the said conventional cable.

In particular, the step of increasing the reactance of the said coaxial superconducting cable comprises the step of connecting in series with the said coaxial superconducting cable an inductance, preferably made from superconducting material.

Advantageously, the method also comprises the step of associating with the said coaxial superconducting cable a parallel conducting path in such a way that the maximum temperature reached by the said coaxial superconducting cable is lower than the minimum temperature between the critical temperature of the superconducting material and the boiling point of the coolant fluid at the minimum working pressure of the fluid.

In a fourth aspect, the present invention relates to a thermally insulated terminal for connection between a multiple-phase cable and an electrical installation at ambient temperature, the said cable comprising, for each phase, at least one coaxial unit having a phase superconductor, a coaxial return superconductor and an interposed layer of electrical insulation, and also thermal control means for maintaining the said superconductors of each of the said coaxial units in the superconducting state, the said terminal being characterized in that it comprises an inductor connected in series with each phase superconductor.

Preferably, the terminal comprises: -at least one casing, -cooling means, -a live current lead for each phase superconductor, having a corresponding phase connector for connection to the said installation at ambient temperature, the said current lead being provided with a resistive conductor between the phase superconductor and the said connector of the current lead, the areas of connection between the said resistive conductors and the said phase superconductors being located inside the casing.

Preferably, the terminal comprises: -a single return current lead provided with a single resistive return conductor, with an upper end connected to a return connector for connection to the installation at ambient temperature; -connecting means made from a superconducting material between the said return superconductors and the said single resistive return conductor, the area of the junction between the said connecting means

made from a superconducting material and the said single resistive return conductor, and at least the said connecting means between the return superconductors and the said single resistive conductor, being inside the casing and being at a temperature below the critical temperature corresponding to the superconducting state owing to the presence of the said cooling means.

The present invention will be more clearly understood with the aid of the following description and the attached figures of examples of embodiments of the present invention, in which:
Figure 1 shows a superconducting three-phase cable;
Figure 2 shows a connecting terminal for three coaxial superconducting cables;
Figure 3 shows schematically a distribution line according to an example of an embodiment of the invention;
Figure 4 shows the terminal in Figure 2 according to an example of an embodiment of the invention;
Figure 5 shows schematically a radial transmission line.

With reference to Figure 1, an example of a three-phase superconducting cable 1 according to the present invention comprises three conducting elements C indicated by C1, C2, C3 respectively, one for each of the phases, preferably housed loosely inside a tubular containing casing 8, made for example from a metallic material such as steel, aluminium or the like.

Each of the conducting elements C in turn comprises a pair of coaxial conductors, namely the phase conductor 2 and the return conductor 4, each of these including at least one layer of superconducting material.

The coaxial phase conductor 2 and return conductor 4 are electrically insulated from each other by the interposition of a layer 3 of dielectric material. In the example illustrated, the superconducting material is incorporated in a plurality of superimposed strips wound on a tubular supporting element 5 and on the electrical insulation 3 respectively.

The cable 1 also comprises appropriate means for cooling the superconducting conductors 2 and 4 to a temperature sufficiently lower than the critical temperature of the previously selected superconducting material, which in the cable in Figure 1 is of the type called"high-temperature".

The aforesaid means comprise suitable pumping means, which are known per se and therefore are not shown, designed to supply an appropriate coolant fluid, for example liquid nitrogen, at a temperature typically ranging from 65 to 90 K, both into the interior F1 of each of the conducting elements C and into the interstices F2 between these elements and the tubular casing 8.

Outside the return conductor 4 there is a metal protective element 6 for short circuits and then a mechanical protective element 7.

In order to reduce to a minimum the dissipation of heat towards the external environment, the superconductor is enclosed within a containing structure, or cryostat, comprising a thermal insulator, formed, for example, by a plurality of superimposed layers of insulating material, and at least one protective sheath.

A cryostat, which is known in the art, is described for example in an article in IEEE Transactions on Power Delivery, vol. 7, no. 4, October 1992, pp. 1745-1753.

More particularly, in the example illustrated, the cryostat comprises a layer 9 of insulating material, consisting, for example, of a plurality (a few tens) of strips of metalcoated plastic material (polyester resin for example), known in the art as"thermal superinsulation", wound loosely, with the aid of interposed spacer elements (not shown) if necessary.

These strips are housed in an annular gap delimited by the casing 8 and a tubular element 10, in which a vacuum of the order of 10-2 N/m2 is maintained by equipment which is known per se.

The tubular element 10, made from metal, is capable of imparting the desired waterproofing to the annular gap, and is covered with an outer sheath 11, made for example from polyethylene.

The metal tubular element 10 is preferably formed from a strip curved into a tubular shape and welded longitudinally, made from steel, copper, aluminium or the like, or from an extruded tube or similar element.

The element 10 may be corrugated if this is necessary to meet the requirements for flexibility of the cable.

In one embodiment, the superconducting material of the cable is formed by strips based on superconductors, known as high-temperature superconductors, of the ceramic type.

More particularly, in this embodiment the superconductor strips are wound around the tubular cylindrical support 5, having a diameter of 15-80 mm, and around the electrical insulation 3, with winding angles with respect to the direction of the cable which are constant or variable between strips and within each strip, and typically ranging from 10 to 60 .

The high-temperature superconductor strips comprise, inside a casing made from silver or similar metal alloy, superconducting materials, of which it is expedient to use

those known in the field by the symbol BSCCO, having the formula: BiaPbpSryCasCuEOX where a is a number from 1.4 to 2.0 ; p is a number from 0 to 0.6; y is a number from 1.5 to 2.5; 8 is a number from 0 to 2.5; s is a number from 1.0 to 4.0; and x is the stoichiometric value corresponding to the various oxides present.

According to the present invention, if it is desired to have a rapid, or even instantaneous, restoration time of the superconducting cable after a short circuit, or in other words a restoration time which is such that the temperature rise of the superconducting cable is limited, the tubular cylindrical support 5 and the protective layer 6 preferably consist of a conducting material, for example copper or aluminium of suitable dimensions. The elements 5 and 6 are associated with the strips of the superconducting cable in such a way that there is an electrical connection between them. In this way, in case of overcurrent, the superconductor passes into the resistive state, and the overcurrent flows in the conduction path parallel to the superconducting cable formed by the metals of the elements 5 and 6. The quantity of conductive metal material in the elements 5 and 6 is such that the maximum temperature reached by the superconducting cable is lower, with a predetermined safety margin, than the minimum temperature between the critical temperature of the superconducting material and the boiling point of the coolant fluid (nitrogen) at the minimum working pressure of the fluid.

Preferably, the superconducting strips comprise at least one reinforcing strip (not illustrated) of metallic material (stainless steel, bronze, beryllium, or aluminium) joined to the metal coating of the strips. The presence of this reinforcing strip makes it possible to increase the resistance of the cable to the various mechanical or thermal stresses imparted to it during installation or use.

According to a further embodiment of the present invention, the support 5 is of composite type and comprises a plurality of adjacent annular sectors of metallic material and plastic material (for example Teflon). This element 5 thus has a coefficient of thermal expansion greater than that of the superconducting material and is therefore able to contract to a greater degree than the superconducting material during the step of cooling of the cable, without inducing stresses inside the superconducting material by interfering with it.

The number of metal and plastic sectors and the positioning of these sectors can be determined by a person skilled in the art according to the design requirements of the cable.

Advantageously, the support 5 thus carries out a plurality of functions simultaneously. One of these is to limit the longitudinal deformations of the layer of superconducting material due to the impeded thermal expansions during the cooling of the superconducting cable after it has been installed (at ambient temperature). One is to mechanically support the superconducting material, and another is to reduce the

stresses exerted by the ends of the superconducting cable on the terminals of the cable, while at the same time providing sufficient metal to stabilize the cable during the transient short circuit.

A type of three-phase coaxial superconducting cable has been described by way of example, but other types of cable may be used in accordance with the present invention, for example mono-phase cables, or mono-element cables (in other words separate cables for each phase); the cryostat may also be constructed differently, for example with the electrical insulation kept at ambient temperature.

The superconducting cables are generally connected to the substations or to the transformer stations of the distribution or transmission network by means of connection terminals such as, for example, those described in European Patent Application EP 780926 in the name of the present Applicant.

A terminal for connection between three mono-phase coaxial superconducting cables cooled to below their critical temperature and the corresponding terminals at ambient temperature, described in the above patent application, is shown in Figure 2.

The system for cooling the cables and terminal is not described here, since it is well known to those skilled in the art.

Principally, the terminal comprises a cold area A within which the parts of the cable are kept below its critical superconductivity temperature, a thermal insulation area B located around the area A, and a heat control area C, in which means are provided to counteract the penetration of heat from the exterior at ambient temperature towards the cold area of the cable.

The lower portion of Figure 2 shows the entry into the terminal of three coaxial cables, each of the mono-phase type, belonging to the single cable 1.

More precisely, each live phase superconductor 102 extends into the cold area and is connected by a terminal clamp 108 to a resistive conductor 109; in turn, the conductor 109 passes through the heat control area C and is finally connected to a connector 119 of the electrical installation at ambient temperature.

From their entry into the cold area, the three return superconductors 104 are interconnected by superconducting connecting means 104', and are connected by means of a clamp 108'to a single current lead formed by a resistive conductor 109'which extends towards the exterior like the other phase conductors through the connector 120.

The superconducting connecting means comprise a superconducting element formed

in accordance with the particular arrangement of the final part of the return conductors.

As will be seen in Figure 2, the cold area of the terminal is delimited by a casing 111 of metallic material, into which a coolant fluid, preferably liquid nitrogen at a temperature of approximately-200 C, is injected through an inlet tube 112.

The injection of liquid nitrogen into the casing at a given temperature and the degree of thermal insulation around the casing are controlled in such a way that the cold area of the casing is always at a temperature below the critical temperature, in other words the temperature above which the superconductors would cease to behave as superconductors.

The thermal insulation area around the casing is provided by a container 113 which delimits a space, in which a vacuum is maintained, around the casing.

The three single-core cables, each of which is kept below the critical temperature by means of liquid nitrogen circulating inside it as shown in the figure by the inlet and outlet tubes 114 and 114', are brought to the entry of the container and of the casing.

The phase conductor 109 and the return conductor 109'pass through the cover of the casing and of the container remaining inside high-and low-voltage insulators 115 and 116 respectively.

The lower portion of the internal surface of each insulator is shaped in the form of a truncated cone opposing, and spaced apart from, a deflector cone 117 around the phase superconductor, for the purpose of controlling the electrical field.

An electrical power transmission/distribution system, shown schematically for illustrative purposes in Figure 3, will now be considered.

This network comprises a plurality of cables 20,30,40, 50,60,70 and 80, which extend between a node 42, connected to a generator 41, and a node 43 which is connected to a load of any kind 44.

The cables 20,30,40,50,60,70 and 80 are considered to consist of conventional, non-superconducting cables, with which a characteristic impedance can be associated.

It will now be assumed that the conventional cable 60 is replaced with a coaxial superconducting cable of equal length.

This cable, by its very nature, has a characteristic impedance which is much smaller than the impedance of the replaced conventional cable.

In the event of a short circuit, for example in the case in which the node 43 is brought to earth potential, there will be a flow of (short-circuit) current between the node 42 and the node 43, passing through the conductors of the network. Owing to the difference in impedance between the cable 60 (with practically zero impedance) and the remaining cables, most of the current will flow in the cable 60.

This also causes an excess current load in the cables connected to the cable 60; in particular, there will be a considerable inflow of current into the cables 20 and 30, greater than that which would occur if the cables were all of the conventional type, thus possibly causing damage to the network.

A similar situation would also occur if a new coaxial

More particularly, it has been calculated that if a complex mesh network (such as that required for supplying a major urban center, for example) were constructed with superconducting cables, there would be an increase in short-circuit current of up to 70% with respect to if this network were constructed with conventional cables.

According to the present invention, the Applicant has found that these problems are resolved by making the electrical behavior of the coaxial superconducting lines in the presence of overcurrents substantially identical to that of similar lines using conventional cables.

In particular, it has found that, by connecting the coaxial superconducting cable in series with an inductive element having a value of reactance such that the total value of reactance (for the cable and inductor) is equal or close to (of the same order of magnitude as) that of a conventional cable for the same connection, the behavior of the network in the presence of overcurrents is brought back to that found when the network consists of cables entirely of the conventional type.

Figure 4 shows a particular embodiment of a connecting terminal according to the invention, comprising a connecting terminal similar to that described previously with reference to Figure 2. In Figure 4, the same numerical references as in Figure 2 are used to indicate components of the same type.

The lower portion of Figure 4 shows the entry into the terminal of the three coaxial cables belonging to the cable 1. The three return superconductors 104, from the entry into the cold area A, are interconnected by superconducting connecting means 104', and are connected, through a clamp 108', to a single current lead formed by the resistive conductor 109'which is extended towards the exterior by the connector 120.

The three phase superconductors 102, of suitable dimensions, which extend inside the casing 113', are wound in such a way as to form three reactance coils 122 with a value determined as described previously.

The three coils 122 should preferably be positioned in such a way as to prevent mutual induction.

In a similar way to that described with reference to the terminal in Figure 2, each live phase superconductor 102 extends into the cold area A and is connected by a clamp 108 to a resistive conductor 109; in turn, the conductor 109 passes through the heat control area C and is finally connected to a connector 119 of the electrical installation at ambient temperature.

The reactance coils 122 are preferably located inside the terminal, but may be located at any point along the superconducting cable. Additionally, because of problems of size or various other factors, the reactance coils 122 may, for example, be distributed between the two terminals (for example by dividing the reactance into two parts), and may in any case be divided into a plurality of parts and located at a plurality of points along the superconducting cable.

A numerical example of a method of designing a connecting line according to the invention is shown below.

Figure 5 shows schematically a generator 41 connected to a network 100. A connecting line 90 connects the network 100 to a load 44.

The connection made by the line 90 has the following characteristic parameters:
Power P = 108 MVA
Voltage V = 115 kV
Frequency f = 60 Hz
Length L = 8 km
Using these parameters it is possible to determine, by a method known to those skilled in the art, in a first approximation, the characteristics of the cable suitable for this connection.

The term"conventional cable suitable for this connection" denotes a cable capable of transmitting electrical power in a connection having predetermined characteristic parameters. For example, the principal characteristic parameters of a connection, such as those listed above, namely power, voltage, frequency and length, may be used, in a first approximation, to determine using known methods the cable section of the three-phase group of three cables suitable for this connection. Consequently it is possible to determine the reactance of the individual cable using known methods.

A possible embodiment of the connection specified above with conventional cables comprises the use of a group of three copper cables with a section of 500 mm2.

In this case, the inductive reactance of the individual conventional cable, which

depends on the type of conductor and on the closeness to the other conductors, is:
Xconv = 0.16 ohm/km
If it is now assumed that a short-circuit current of 5000 A reaches the connection 90 from the external network 100, it is found, by methods of calculation known to persons skilled in the art, that there will be an overcurrent of approximately 4190 A at the end of the connection 90, in other words at the end near the load 44.

The connecting line 90 specified above, if formed by using a group of three coaxial superconducting cables, has an inductive reactance of the individual superconducting cable equal to:
Xsup = 0.0264 ohm/km
The Applicant has observed that the value of reactance of the coaxial superconducting cable is considerably lower than that of the conventional cable and equal, in the example shown, to approximately one sixth.

If it is now assumed that a short-circuit current, again having a value of 5000 A, reaches the connection from the network 100 outside the connection 90, formed in this case with coaxial superconducting cables, there will be an overcurrent of approximately 4500 A at the end of the connection, with an increase of approximately 7% by comparison with the previous case.

According to the present invention, after the three return superconductors of the cables have been connected together and to the earth in a similar way to that described with reference to Figure 4, a solenoid is formed on the conductor of each phase, and has the following reactance:
Xadd = Xconv-Xsup = (0.16-0.0264) ohm/km = 0.1336 ohm/km and therefore the following inductance
Ladd = Xadd/(2sf) = 0. 354(2sf) = 0. 354 mH/km where
Xadd is the reactance to be connected in series with the individual phase for each km of the connection;
Xconv is the reactance of the conventional cable for each km of the connection;
Xsup is the reactance of the coaxial superconducting cable for each km of the connection;
Ladd is the inductance to be connected in series with the individual phase for each km of the connection.

In this way an effect similar to that of a conventional cable, in other words that of canceling the increase in the aforementioned short-circuit value, is obtained. The connection 90, therefore, behaves in the presence of a short circuit as if it had been constructed with conventional cables.

An inductive element having Ladd = 0.354 mH/km x 8 km = 2.83 mH is obtained, for example, by constructing a solenoid with the outgoing conductor of each phase of the superconducting cable. The characteristics of this solenoid are: number of turns = 26

turn radius = 1.5 m height of winding = 2 m length of conductor = 245 m
The additional inductive element, according to a further embodiment of the invention, may comprise a solenoid having a suitable magnetic core whose characteristics become, for example: number of turns = 1 turn radius = 0.5 m height of winding = < 0.2 m length of conductor = 3.14 m
In this example, it is assumed that the coaxial superconducting cable is connected in series with a reactance whose value is equal to the difference between the reactance of a conventional cable and the reactance of the superconducting cable, in such a way that the value of reactance for the conventional cable, which is suitable for this connection, is substantially the same as that of the superconducting cable. However, it is possible to connect a reactance whose value is equal to a fraction of the aforesaid reactance (equal to half, for example) by accepting, if the components of the system permit, the relative increase in the short-circuit current. For example, if a reactance whose value is equal to half that of the conventional cable:
Xaddl = (Xconv-Xsup)/2 = (0.16-0.0264)/2 ohm/km = 0.0668 ohm/km is connected in the connection described previously, the increase in the short-circuit current is approximately 4%.

It is also possible to connect the coaxial superconducting cable in series with a reactance whose value is such that the total reactance exceeds that of a conventional cable in such a way as to provide better behavior than that of a conventional cable. In any case, in order to make a connection using coaxial superconducting cables substantially compatible with an equivalent conventional cable suitable for this connection, the reactance of the superconducting cable must be increased, and must preferably be of the same order of magnitude as that of the conventional cable.

The Applicant notes that the additional inductive element may be located preferably at any of the ends of the phase superconductor and preferably in that area of the terminal where the superconducting cable is connected to the conventional cables at ambient temperature.

According to a further embodiment, it is possible to use two additional inductive elements located at both ends of the phase superconductor and having a total value of inductance equal to that determined as described above.

The aforesaid inductive element may also be made from a conventional conductor (made of copper, for example) placed in air at ambient temperature.

The Applicant observes, however, that the invention is particularly advantageous if this inductive element is made with the same superconducting cable without the return conductor. This is because this method considerably reduces the resistive losses generated throughout the length of the conductor used to form the solenoid. In the case in question, the losses of a solenoid formed from a copper conductor having a section of 500 mm, for example, are of the order of 12 W/m/phase, while the losses of

the solenoid formed from a superconductor are of the order of 6 W/m/phase (including the cooling efficiency).

Additionally, both the superconducting cable and the additional inductive element may advantageously have the metal or composite type of support as described previously.